Global NEST Journal, Vol 10, No 2, pp 174-182, 2008

CO_2 CONTROL BY MEANS OF THE INCREASED PENETRATION OF DIESEL PASSENGER CARS IN FINLAND

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Received: 22/05/07
Accepted: 12/07/07

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ABSTRACT

One efficient way to control the CO_2 emissions from the transport sector is the replacement of gasoline passenger cars by Diesel ones, which emit less CO_2. This can be more effective in Finland, where the Diesel penetration is only 13.6%, which is very low compared to the other member countries of the European Union. The benefit in CO_2 emitted from the new passenger cars is studied in the case of an increased Diesel penetration in this country, after several scenarios using the current and estimated future passenger car registrations and the fuel consumption. The results show that, in the case of new passenger cars, a CO_2 benefit of more than 2.6% can be achieved, if a Diesel penetration higher than 30% occurs in the case of the current fleet. If the penetration reaches 50%, this benefit reaches 5.9%. Future total CO_2 emissions from transport sector will increase significantly and can be partially controlled by the introduction of Diesel passenger cars or the replacement of heavy passenger cars by lighter ones.

KEYWORDS: Carbon Dioxide, Diesel, Gasoline, Finland, Passenger Cars

INTRODUCTION

The majority of human energy production activities are based on the combustion of carbon-containing fuels and consequently they produce CO_2, which is released to the atmosphere. As the CO_2 emissions are responsible for the greenhouse effects, several ways are searched to control and decrease them. For example, the Kyoto protocol (United Nations 1992), which is signed from many of countries, is an agreement for the control of CO_2 emissions.

The transport sector is one of the main anthropogenic CO_2 sources (Ellis and Treanton, 1998; Kram *et al.,* 2000). Even if modern vehicles emit less CO_2 compared to the older ones, the total CO_2 emissions increase due to the increase in the number of passenger cars, the number of driven distance, the increase in vehicle weight (due to the addition of more auxiliaries), the addition of more power consuming devices and emission control. The control of CO_2 emitted from passenger cars could help to decrease the total CO_2 emissions.

One effective way to control the transport CO_2 emissions is the replacement of a part of gasoline passenger cars by Diesel ones, as the latter ones, due to their greater thermodynamic efficiency, emit less CO_2 for the same power demand.

A previous study (Sullivan *et al.,* 2004), showed a significant decrease of CO_2 emissions in the USA by the introduction of Diesel passenger cars. This study did not take into account a sales-weighted approach. Such an approach can better predict future CO_2 emissions as it takes into account the real market conditions of each country (Zervas and Bikas, 2005; Zervas, 2006).

The average current (in 2003) Diesel penetration is quite high in the 15 countries of European Union (ACEA, 2005; Eurostat, 2005; CCFA, 2005); however, there are quite important differences between each country. In 2003 year, the Diesel penetration was around 60% in France, Austria and Belgium, but remained only 14% in Finland (ACEA 2005; Eurostat, 2005; CCFA, 2005). An increase in the Diesel penetration in this country could help to control the CO_2 emissions of the transport sector, which were estimated to correspond to 23% of the total CO_2 emissions in Finland in 1998 (Transport Sector report, 1998).

In order to estimate the CO_2 benefit due to the increased Diesel penetration in Finland, the current market of passenger cars is first analyzed and the future (in 2020) market is estimated. Several scenarios, taking into account the number of new passenger cars in 2020, the segment distribution and the fuel consumption are constructed. The CO_2 emissions are estimated for each scenario and compared to the current situation to assess the CO_2 changes.

ASSUMPTIONS AND METHODOLOGY USED

The data used here come from the internet sites of Eurostat, Association of European Automobile Manufactures (ACEA), Committee of French Automobile Manufactures (CCFA) World Resources Institute (WRI), International Road Federation (IRF), and Finnish Statistics Net (FSN). The weight and CO_2 emissions (obtained on the New European Driving Cycle (NEDC)) of each passenger car are obtained from the German Federal Motoring Authority (KBA, 2003 data, 2005).

The current passenger car market in Finland is analyzed and compared with the average market of the European Union (EU, 15 countries). According to this analysis, several scenarios for the Finnish market in 2020 are established. The changes in CO_2 emissions are calculated for different percentages of Diesel penetration in the Finnish market. The CO_2 emissions of the KBA file are used, assuming the same annual mileage for the current and future gasoline and Diesel passenger cars. In a first stage, the CO_2 emissions are calculated using the current data; in a second one, the future CO_2 emissions are estimated taking into account the most probable future technologies (Sullivan *et al.,* 2004). This study is limited to CO_2 emissions from new registered passenger cars.

ANALYSIS OF THE FINNISH MARKET

At the first stage, the Finnish passenger car market is compared with the average market of the EU. Figure 1 shows the percentages of Finnish population and passenger cars. From 1970 to 2003, the Finnish population percentage is almost constant and corresponded to 1.37% in 2003, while the percentage of the passenger car fleet constantly increased until 1990: from 1.14% in 1970, it reached 1.33% in 1990. However, a decrease is observed after this year and this percentage is now quite stable at around 1.16-1.18%. Although this percentage has been quite constant over the last 6-7 years, “Finnish Statistics Net” ((Internet site of FSN, 2005) predicts an increase in the future.

The number of passenger cars per 1000 inhabitants is another characteristic parameter (Figure 1). The average EU number in 2001 was 488 PC per 1000 inhabitants, while that of Finland was 414, corresponding to 85% of the average EU number. This percentage increased from 80% to 100% between 1970 and 1990, and then decreased to reach about 83% in 1995. After that year it remains relatively constant.

The Finnish passenger car fleet increases by the new car registrations and by an increase of the average age of the already registered vehicles. For both parameters, an important difference exists between the Finnish and the average EU market. In 2003, 27 new PC/1000 inhabitants were registered in Finland, which is much lower than the 34 PC registered in EU (figure 1, upper curves). This statement indicates that the Finnish new passenger cars market may increase in the future. Moreover, the Finnish fleet is older than the average EU age, 9.8 years in Finland against 7.6 in the EU in 1999 (EU, 2003).

The Diesel penetration is quite different between the Finnish and average EU market. The Diesel percentage was only around 10% in 1980 in most of the EU countries, but increased sharply to reach almost 60% in 2003 in several countries, like Austria, France and Spain (Internet site of ACEA 2005; Internet site of CCFA 2005). However, in 2003, this percentage was only 13.6% in Finland. An important CO_2 benefit could be obtained in Finland if this percentage approached the EU average.

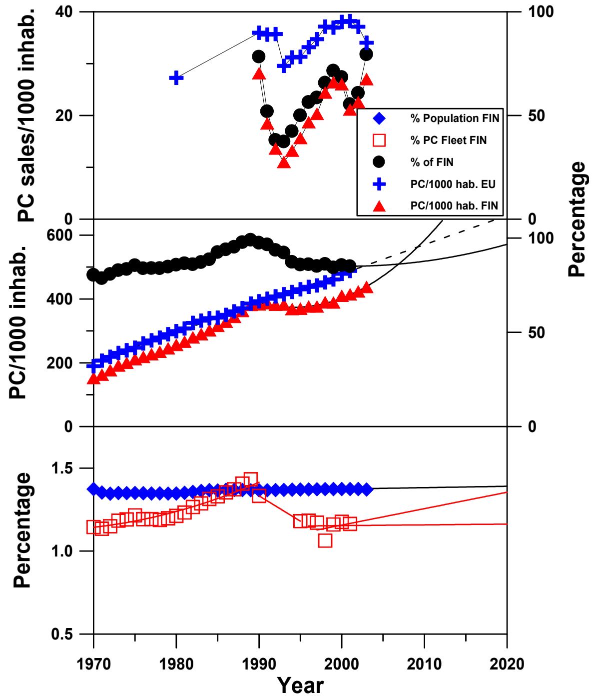

Figure 1. Lower curves: percentage of the Finnish population and passenger car fleet in European Union. Middle curves: number of PC/1000 inhabitants in the EU and in Finland and the percentage of the Finnish number over the EU one. Upper curves: number of the new PC registrations/ 1000 inhabitants in the EU and in Finland and the percentage of the Finnish number over the EU

Another difference between the Finnish and EU markets is segment distribution. Table 1 presents the main characteristics of each of the 11 segments of the European and Finnish fleets: average weight, average CO_2 emissions on the NEDC and registrations percentage in 2003. The majority of the EU average and Finnish market corresponds to four classes: “Economic”, “Small Car”, “Lower Medium” and “Upper Medium”. However, table 1 presents that the Finnish market is dominated by heavier passenger cars than the EU average. This indicates that for the same number of passenger cars and the same annual mileage, the CO_2 emissions would be higher in Finland because heavier passenger cars compose its fleet.

CO_2 EMISSIONS FROM GASOLINE AND DIESEL PASSENGER CARS

There is a relationship between the CO_2 emissions of gasoline and Diesel passenger cars and their weigh: $CO_2=0.1479*Weight-7.9$ and $CO_2=0.1133*Weight-8.2$ for gasoline and Diesel passenger cars respectively, using the 2003 KBA data (Zervas and Bikas, 2005). For the above relationships, no distinction is made between manual and automatic transmission (even if this parameter has a small influence on CO_2 emissions (Sullivan *et al.,* 2004)), because in 2003 more than 84 % of the Finnish car fleet was equipped with manual gearbox.

We assume that an eventual replacement of gasoline passenger cars by Diesel versions would occur within the same segment rather within the same weight class. Using the 2003 data, two new lines are now obtained: $CO_2=0.1702*Weight+6.7$ and $CO_2=0.1398*Weight-11.0$ for gasoline and Diesel passenger cars respectively (Zervas and Bikas*,* 2005). The last two equations are used in this work. A closer analysis about those relationships are presented elsewhere (Zervas and Bikas*,* 2005; Zervas 2006).

Table 1. The 11 segments of the EU and Finnish PC fleet. RSD: relative standard deviation

Segment	GASOLINE						DIESEL					
	Weight		CO_2 emissions		Registrations in 2003 (%)		Weight		CO_2 emissions		Registrations in 2003 (%)	
	Average (kg)	RSD (%)	Average (g km^{-1})	RSD (%)	EU	FIN	Average (kg)	RSD (%)	Average (g km^{-1})	RSD (%)	EU	FIN
Economic	839	9.9	151	16.1	10.9	1.03	900	9.0	121.6	17.2	0.98	0.02
Small car	947	9.6	168.5	15.1	37.5	18.9	1021	8.7	138.5	13.5	18.0	5.1
Lower Medium	1138	9.7	196	14.3	27.9	39.7	1217	8.2	153.6	12.9	36.4	33.1
Upper medium	1340	9.0	222.5	14.1	13.7	31.3	1396	8.2	173.5	14.9	23.5	36.2
SUV(<4m50)	1345	11.7	232.8	12.2	1.6	1.9	1631	11.3	227.5	14.5	6.41	1.38
4x4 (<4m50)	1406	25.1	265.6	25.9	0.58	0.25	1749	21.4	260.2	16.2	2.12	2.83
Superior	1510	8.1	259	15.0	4.4	5.3	1568	6.0	200.9	14.5	4.3	17.6
Compact/People Carrier	1697	8.0	266.2	12.9	0.78	1.1	1716	8.2	196.2	12.3	1.35	0.79
Prestige	1712	16.9	336.3	27.1	1.09	0.11	1779	8.5	230.4	11.7	0.35	0.12
4x4 (>4m50)	1982	10.2	342.8	11.3	0.08	0.04	1969	8.3	285.6	10.6	0.77	0.98
SUV(>4m50)	2004	7.0	342.7	13.4	0.66	0.23	1970	8.0	256.6	9.42	2.0	1.97

However, the future fuel consumption will change. A previous work (Zervas and Bikas, 2005) reports some estimation about the future gasoline and Diesel fuel consumption. Four assumptions are used in this work for the future fuel consumption:

- the *Diesel optimistic and pessimistic assumptions* (*DO, DP*) presumes 0 and +5% change respectively in Diesel fuel consumption,
- the *gasoline optimistic and pessimistic assumptions* (*GO, GP*) presumes -10% and -5% change respectively in gasoline fuel consumption,

After the inclusion of these fuel consumption changes, the lines linking the CO_2 emissions with the passenger cars weight are: *GO*: $CO_2=0.1617*Weight+6.7$, *GP*: $CO_2=0.1532*Weight+6.7$, *DO*: $CO_2=0.1398*Weight-11.0$ and *DP*: $CO_2=0.1468*Weight-11.0$.

SCENARIOS USED FOR THE FUTURE FINNISH PASSENGER CARS MARKET

Based on the analysis of the Finnish and EU new passenger cars market, twenty scenarios are constructed to estimate the changes in CO_2 emissions, for different percentages of Diesel penetration (Table 2). These scenarios are divided in four groups:

1. The scenarios using the current Finnish new passenger car registrations (scenarios 1-5, named *FIN*).
2. The scenarios using the average value between the current Finnish and the current EU new passenger car registrations. The percentage of each segment corresponds to the average value between the current Finnish and the current EU percentages (scenarios 6-10, named *FIN/EU*).
3. The scenarios using the average value between the current Finnish and the current EU new passenger car registrations, by maintaining the current Finnish segment distribution (scenarios 11-15, named *FIN/EU1*).
4. The scenarios using the current EU new passenger car registrations (scenarios 16-20, named *EU*).

RESULTS AND DISCUSSION

CO_2 change using the current Diesel penetration and the future fuel consumption

Figure 2 shows the CO_2 changes in the case of current Diesel penetration for the five groups of scenarios used and for the current and future fuel consumption. The following comparisons are performed:

- influence of new PC registrations in the case of the *CFC* scenarios.
- influence of fuel consumption in the case of the current registrations (*FIN* scenarios)
- influence of the fuel consumption in the case of future registrations (*FIN/EU, FI1/EU* and *EU* scenarios).

It must be noted that for all cases presented here, the scenarios using the Diesel optimistic and pessimistic (*DO* and *DP*) fuel consumption give quite similar results (with the *DP* scenarios always having slightly higher CO_2 emissions), because the current Diesel penetration is low. The scenarios using the gasoline and Diesel optimistic fuel consumption (*DO* and *GO*) always give slightly higher CO_2 benefit than those using the pessimistic one (*DP* and *GP*), because the fuel consumption is lower in the first case.

Table 2. The 20 scenarios used

Scenario	Name	Assumptions for the future PC registrations in Finland		Assumptions for the Fuel Consumption
		New PC registrations	Segments	
1-5	*FIN-CFC / FIN-GODO / FIN-GODP / FIN-GPDO / FIN-GPDP*	as the current Finnish ones	as the current Finnish ones	Current / *GODO / GODP / GPDO / GPDP*
6-10	*FIN/EU-CFC / FIN/EU –GODO / FIN/EU –GODP / FIN/EU –GPDO / FIN/EU -GPDP*	average between the current Finnish and current EU ones (corresponding to 31 new PC registr./1000 inhab./year)	average between the current Finnish and current EU	Current / *GODO /GODP / GPDO /GPDP*
11-15	*FIN/EU1-CFC / FIN/EU1-GODO / FIN/EU1-GODP / FIN/EU1-GPDO / FIN/EU1-GPDP*	average between the current Finnish and current EU ones (corresponding to 31 new PC registr./1000 inhab./year)	as the current Finnish ones	Current / *GODO /GODP / GPDO /GPDP*
16-20	*EU-CFC / EU-GODO / EU-GODP / EU-GPDO / EU-GPDP*	as the current EU average (34 new PC registr./1000 inhab./year)	as the current EU average	Current / *GODO / GODP / GPDO / GPDP*

Influence of the number of new registered passenger cars registrations by maintaining the current fuel consumption (CFC). Assuming that in the future the fuel consumption remains as the current one, there is a strong increase of CO_2 emissions with the new passenger car registrations (scenarios *EU-CFC>AVERAGE1-CFC>AVERAGE-CFC>FIN-CFC*). Figure 2 shows that the CO_2 benefit from the use of lighter passenger cars in Finland is counteracted by the increase of the total new cars number (scenario *FIN/EU-CFC*, with a CO_2 increase of 5.0%). If new passenger car registrations rise keeping the current Finnish segment distribution (scenario *FIN/EU1-CFC*), CO_2 emissions will increase even more (10.3%), while the *EU-CFC* scenario gives an increase of 12.6%. Such results indicate that beside the influence of registrations vehicle weight and segment distribution play an important role on CO_2 emissions. This is also evident if we consider the increase in CO_2 between scenarios 6 and 11, where the registrations are maintained constant, while the assumed segment distributions are different between one another.

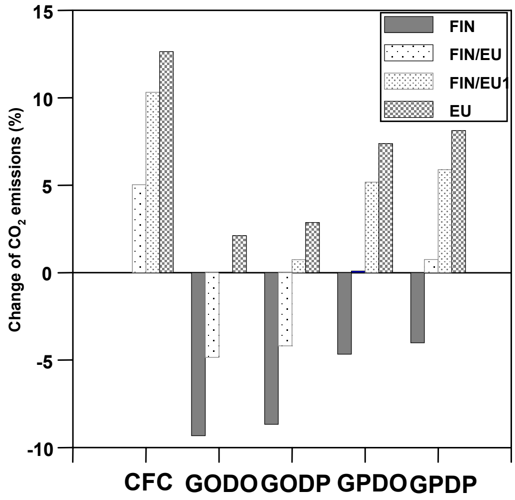

Figure 2. Change in total CO_2 emitted from new passenger cars, in the case of no supplementary introduction of Diesel PC in Finland, for the different registrations and fuel consumption scenarios used

Influence of future fuel consumption using the current registrations (FIN scenarios). Assuming that the passenger car registrations in Finland remain unchanged in the future, a decrease in future CO_2 emission for all assumptions of future fuel consumption is observed. That decrease will be about 4.0-4.6% in the case of a small decrease in gasoline fuel consumption (the two *GP* assumptions), but will reach 8.6-9.3% in the case of a greater decrease (the two *GO* assumptions), indicating the major importance of future fuel consumption and its implications in CO_2 emissions.

Influence of new passenger cars registrations using the future fuel consumption. Using the future optimistic gasoline fuel consumption, the CO_2 decrease will be quite high (8.6-9.3%) in the case of the two current registrations scenarios (*FIN-GO*). The CO_2 increase due to the increased passenger cars registrations could even be counteracted by the decreased gasoline fuel consumption: a decrease of CO_2 emissions by 4.1-4.8% in the case of *FIN/EU-GO* scenarios and a slight increase of 0.02-0.7% in the case of the *FIN/EU1-GO* ones. However, that gasoline consumption cannot counteract a higher increase of the new passenger cars registrations (the two *EU-GO* scenarios, with an increase of 2.1-2.8% in CO_2 emissions).

In the case of the gasoline pessimistic fuel consumption (*GP*), the CO_2 benefits are lower than in the previous case. The CO_2 changes for the *FIN-GP, FIN/EU-GP, FIN/EU1-GP* and *EU-GP* scenarios are around –4%, -0.8%, 5.5% and 7.3-8.1% respectively. Those results attest to the great importance of future fuel consumption and vehicle weight on the total CO_2 emissions from new passenger cars.

CO_2 change in the case of increased Diesel penetration

Figure 3 shows the change on CO_2 emissions as a function of Diesel penetration in the case of the current fuel consumption. It is clearly shown that, for each scenario, the CO_2 benefit is higher at increased Diesel penetration. The four groups of scenarios form four quite parallel groups of lines. The CO_2 benefit is lower at the increased numbers of new passenger car registrations. Two particular cases will be further examined: 30% and 50% Diesel penetration.

The total CO_2 emitted from new passenger cars decreases by 2.7% and 5.9% respectively in the case of current registrations (*FIN-CFC*). That indicates that an important CO_2 benefit can be immediately achieved in this country by the increased percentage of Diesel passenger cars. The benefit can be cancelled in the case of increased passenger cars registrations. A 30% penetration increases CO_2 emissions by 2.3%, 7.4% and 9.7% in the case of the

FIN/EU-CFC, FIN/EU1-CFC and *EU-CFC* scenarios respectively. A 50% penetration gives better results: a decrease of CO_2 emissions by 1.1% and an increase of 3.8% and 6.2% in the case of the same scenarios. It must be noticed that the above results are better than those obtained in the case of 0% Diesel penetration, which present an increase of 5.0%, 10.3% and 12.6% respectively for these three scenarios. The above results show that, the more the Finnish new passenger car registrations approach the EU average registrations, the more the total CO_2 emissions increase. A higher Diesel penetration could help to partially control this increase.

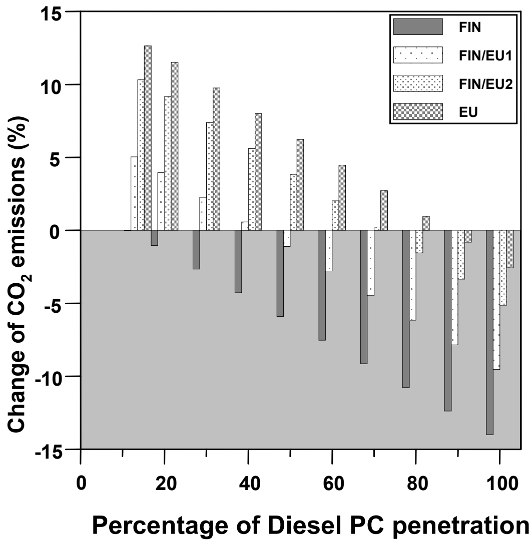

Figure 3. Change in the total CO_2 emitted from new passenger cars from the increased percentage of Diesel PC in Finland, for the different scenarios used in the case of CFC scenarios

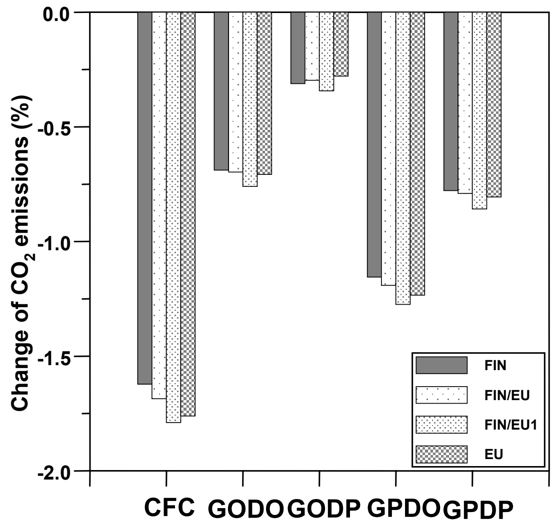

Figure 4. Supplementary change in total CO_2 emissions emitted from new PC, for a 10% supplementary penetration of Diesel PC

The CO_2 emissions are always lower in the case of the future fuel consumption compared to the current one (*CFC*). This difference is 0.5-3 percentage units in the case of the 30% Diesel penetration and reaches 1-7 percentage units in the case of 50%. Naturally, this benefit is higher in the case of optimistic gasoline or Diesel fuel consumption. Those results indicate that a control of future fuel consumption will help to control the future CO_2 emissions.

Another parameter is the CO_2 benefit for a supplementary Diesel penetration of 10% (figure 5). Figure 4 shows that the CO_2 benefit increases with the number of future passenger cars registrations (*EU>FIN/EU1>FIN/EU>FIN)* and can reach 1.8% in the case of scenario *EU-CFC.*

Looking at the different scenarios which consider the future fuel consumption, the following ranking, from high to low benefit in CO_2 emissions with increasing Diesel penetration, is observed: *GPDO>GPDP>GODO>GODP* (figure 5). The reason is that the two first cases study a pessimistic gasoline fuel consumption, which increases the difference between gasoline and Diesel CO_2 emissions, while the last two scenarios an optimistic gasoline fuel consumption, which reduces this difference. The assumptions *GPDO* and *GODO* give respectively more CO_2 benefit than the *GPDP* and *GODP,* because they take into account an optimistic Diesel fuel consumption, which increases the difference between gasoline and Diesel CO_2 emissions, contrary to the latter two assumptions, which decrease that difference.

CONCLUSIONS

The Diesel penetration in Finland is considerably lower than the corresponding EU average value. This work assessed the CO_2 benefit from the increasing penetration of Diesel passenger cars in Finland's car fleet, after twenty scenarios using the estimated future Finnish PC market.

Assuming that future PC registrations remain at the current level and fuel consumption from gasoline PC decreases, there will be a future 4-9% decrease in the CO_2 emitted from the new PC. The CO_2 emissions increase with the number of passenger cars registrations. A partial control of CO_2 emissions increase can be achieved by the shift of vehicle segments distribution to lighter vehicles. If the new registrations reach the same level as the average between the current Finnish and the EU average, in terms of new passenger cars registrations and segment distribution, the total CO_2 emissions will increase by 5%. If the new PC registrations increase keeping the current Finnish segment distribution, the CO_2 emissions will increase by 10%, indicating the high importance of vehicle segment distribution. If the new PC registrations reach the current EU average value, this increase will be 12.6%.

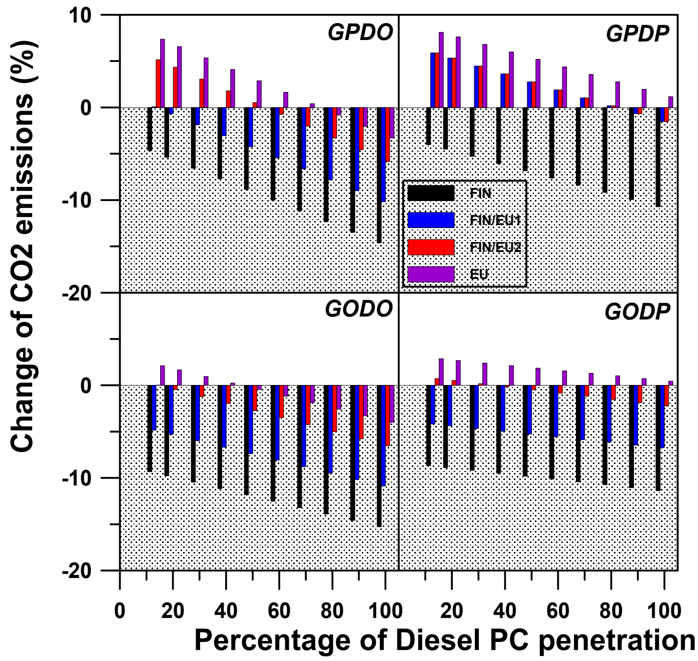

Figure 5. Change in the total CO_2 emitted from new passenger cars from the increased percentage of Diesel PC in Finland, for the different scenarios used in the case of future fuel consumption

A 30% or 50% Diesel penetration decreases the total CO_2 emissions from new passenger cars 2.6 and 5.9% respectively in the case of the actual registrations and actual fuel consumption. The *FIN/EU-CFC, FIN/EU1-CFC* and *EU-CFC* scenarios give an increase of 2.3%, 7.4% and 9.7% respectively for a penetration of 30%, and –1.1%, 3.8%, and 6.2% respectively for a penetration of 50%. The above values are lower than those of the current Diesel penetration. A supplementary penetration of Diesel passenger cars of 10% gives a CO_2 benefit, which can reach 1.8%.

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